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Estimating the Quality of Concrete Bridge Girder Using Ultrasonic Pulse Velocity Test

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ABSTRACT:
This study estimates the quality of concrete bridge girder, an attempt is also made to increase the accuracy of calculating the strength, using the nondestructive test (NDT) Ultrasonic pulse velocity tests. The aim of the present paper is to check the accuracy for assessing concrete bridges girder. This paper reviews various NDT methods available and presents a case study related to the strength evaluation of existing bridge pier. The assessment involves the Ultrasonic pulse velocity tests. Even though there are many methods for Non Destructive Test (NDT) but every method have it own boundaries and which mean the method cannot afford an accurate and consistence result for difference cases and to detect different defect. This paper is an attempt to capture the most current ideas for a very specific application of NDT: determining the condition of reinforced concrete bridges overall and bridge girders, in particular. To this end, attention is given to why NDT is needed and what aspects of concrete condition can be addressed with NDT. Some NDT methodologies that are, or may soon be, promising for concrete applications are discussed. Case studies are presented to demonstrate how NDT can be applied to concrete bridge girders and proposals are made for future areas of study and development. The use of nondestructive testing methods can help reduce the backlog of deficient bridges in two ways. First, these techniques will allow inspectors to get a more accurate view of the condition of a bridge. The second way by which NDT can help is by allowing inspectors to locate damage earlier. The data obtained from each test has been evaluated and the accurate and precise device was determined. From this research, the most accurate NDT method is Ultrasonic Pulse Velocity.

KEYWORDS: *Non Destructive Testing; Bridge Pier; Case Study.*

I. INTRODUCTION

It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the concrete. The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, through those where the concrete surface is slightly damaged, to partially destructive tests, such as core tests and pullout and pull off tests, where the surface has to be repaired after the test. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delamination. Non-destructive testing can be applied to both old and new structures. For new structures, the principal applications are likely to be for quality control or the resolution of doubts about the quality of materials or construction. The testing of existing structures is usually related to an assessment of structural integrity or adequacy. In either case, if destructive testing alone is used, for instance, by removing cores for compression testing, the cost of coring and testing may only allow a relatively small number of tests to be carried out on a large structure which may be misleading. Non-destructive testing can be used in those situations as a preliminary to subsequent coring.

Typical situations where non-destructive testing may be useful are, as follows:
1. Quality control of pre-cast units or construction *in situ.*
2. Removing uncertainties about the acceptability of the material supplied owing to apparent non-compliance with specification.
3. Confirming or negating doubt concerning the workmanship involved in batching., mixing, placing, compacting or curing of concrete.
4. Monitoring of strength development in relation to formwork removal, cessation of curing, prestressing, load application or similar purpose.
5. Location and determination of the extent of cracks, voids, honeycombing and similar defects within a concrete structure.
6. Determining the concrete uniformity, possibly preliminary to core cutting, load testing or other more expensive or disruptive tests.
7. Determining the position, quantity or condition of reinforcement.
8. Increasing the confidence level of a smaller number of destructive tests.
9. Determining the extent of concrete variability in order to help in the selection of sample locations representative of the quality to be assessed.
10. Confirming or locating suspected deterioration of concrete resulting from such factors as overloading, fatigue, external or internal chemical attack or change, fire, explosion, environmental effects.

II. BASIC METHODS FOR NDT OF CONCRETE STRUCTURES

The following methods, with some typical applications, have been used for the NDT of concrete:
1. Visual inspection, which is an essential precursor to any intended non-destructive test. An experienced civil or structural engineer may be able to establish the possible causes of damage to a concrete structure and hence identify which of the various NDT methods available could be most useful for any further investigation of the problem.
2. Half-cell electrical potential method, used to detect the corrosion potential of reinforcing bars in concrete.
3. Schmidt/rebound hammer test, used to evaluate the surface hardness of concrete.
4. Carbonation depth measurement test, used to determine whether moisture has reached the depth of the reinforcing bars and hence corrosion may be occurring.
5. Permeability test, used to measure the flow of water through the concrete.
6. Penetration resistance or Windsor probe test, used to measure the surface hardness and hence the strength of the surface and near surface layers of the concrete.
7. Cover meter testing, used to measure the distance of steel reinforcing bars beneath the surface of the concrete and also possibly to measure the diameter of the reinforcing bars.
8. Radiographic testing, used to detect voids in the concrete and the position of stressing ducts.
9. Ultrasonic pulse velocity testing, mainly used to measure the sound velocity of the concrete and hence the compressive strength of the concrete.
10. Sonic methods using an instrumented hammer providing both sonic echo and transmission methods.
11. Tomography modeling which uses the data from ultrasonic transmission tests in two or more directions to detect voids in concrete.
12. Impact echo testing, used to detect voids, delamination and other anomalies in concrete.
13. Ground penetrating radar or impulse radar testing, used to detect the position of reinforcing bars or stressing ducts.
14. Infrared thermography, used to detect voids, delamination and other anomalies in concrete and also detect water entry points in buildings.

2.1 Ultrasonic Pulse Velocity:-

This method is explained in IS 13311 (part 1):1992, which involves measurement of the time of travel of electronically generated mechanical pulses through the concrete. The ultrasonic pulse velocity method could be used to establish:

a) Homogeneity of concrete
b) Presence of cracks & voids
c) Changes in structures of the concrete
d) The quality of the concrete in relation to standard requirement
e) The values of dynamic elastic modulus of the concrete

The principle behind the Ultrasonic Pulse Velocity is that the pulses are generated by an electro-acoustical transducer, when pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of different material phase within the concrete. A complex system of waves is developed which include longitudinal, shear and surface waves. The receiving transducer detects the onset of longitudinal waves which is the fastest. Because the velocity of the pulses is independent of the geometry of the material through which they pass and depends only on its elastic properties. When quality of concrete in terms of density, homogeneity and uniformity is good, higher velocities are obtained. In case of poorer quality of concrete lower velocities are obtained.

The first waves to reach the receiving transducer are the longitudinal waves, which are converted into an electrical signal by a second transducer. Electronic timing circuits enable the transit time T of the pulse to be measured.

Longitudinal pulse velocity (in km/s or m/s) is given by:

V= L/T

(1)

Where

V is the longitudinal pulse velocity,

L is the path length,

T is the time taken by the pulse to traverse that length.

Pulse velocity measurements made on concrete structures may be used for quality control purposes. In comparison with mechanical tests on control samples such as cubes or cylinders, pulse velocity measurements have the advantage that they relate directly to the concrete in the structure rather than to samples, which may not be always truly representative of the concrete in situ. The typical classification of the quality of concrete on the basis of Ultrasonic pulse velocity is given the Table.1

Table No.1.Classification of the Quality of Concrete on the Basis of Pulse Velocity

Longitudinal pulse velocity		Quality of concrete
Km/s	Ft/s	
>4.5	>15	Excellent
3.5-4.5	12-15	Good
3.0-3.5	10-12	Medium
2.0-3.0	7-10	Poor
< 2.0	<7	Very poor

Factors affecting the pulse velocity:-

i. Surface condition and moisture content

ii. Temperature of concrete

iii. Micro cracks in concrete

iv. Water cement ratio

v. Age of concrete

vi. Presence of steel reinforcement

vii. Type of aggregate

III. CASE STUDY

3.1. General Information:-

The following case studies have been selected to demonstrate the effectiveness for NDT for detecting anomalies in reinforced concrete structures. While the cases do not all deal directly with concrete bridge girders, the methods demonstrated all can be applied readily to girders.

The NDT is applied on New Aatish Market Metro (Phase-I-East West Corridor) at Jaipur Rajasthan. The Jaipur Metro Rail Corporation has entered into an agreement (05.08.2010) with the Delhi Metro Rail Corporation (DMRC) for development of Phase-I-A from Mansarovar to Chandpole on ‘deposit work’ basis covering a length of 9.718 kms and Phase-I-B (Chandpole to Badi Chaupar) covering a length of 2.349 kms. The plan of New Aatish Market Metro Jaipur shown in Figure 1, below, is a reinforced concrete box girder bridge, originally constructed in 2011. It is oriented East West Corridor. This Report is prepared as study about the New Aatish Market Metro Jaipur under Phase-I-East West Corridor. The superstructure of a large part of the viaduct comprises of simply supported spans. However at major crossing over or along existing bridge, special steel or continuous unit will be provided. The standard spans c/c of piers of simply supported spans constructed by precast segmental construction technique has been proposed as 28.0m. The other spans (c/c of pier) comprises of 31.0 m, 25.0 m, 22.0 m, 19.0 m & 16.0 m, which shall be made by removing/adding usual segments of 3.0 m each from the centre of the span. The pier segment will be finalized based on simply supported span of 31.0m and the same will be also kept for all simply supported standard span. The viaduct superstructure will be supported on single cast-in-place RC pier. The shape of the pier follows the flow of forces. For the standard spans, the pier gradually widens at the top to support the bearing under the box webs. The size of pier is found to be 1.6 m diameter of circular shape and height of pier is found to be 5.5 m (from base to cap bottom).

3.2. Scope of work:-

The quality of the concrete was to be evaluated by performing Non-destructive Testing. In order to assess the quality of concrete, the following methods of testing were employed:

(i)Ultrasonic Pulse Velocity test as per IS: 13311-1992 (Part 1).

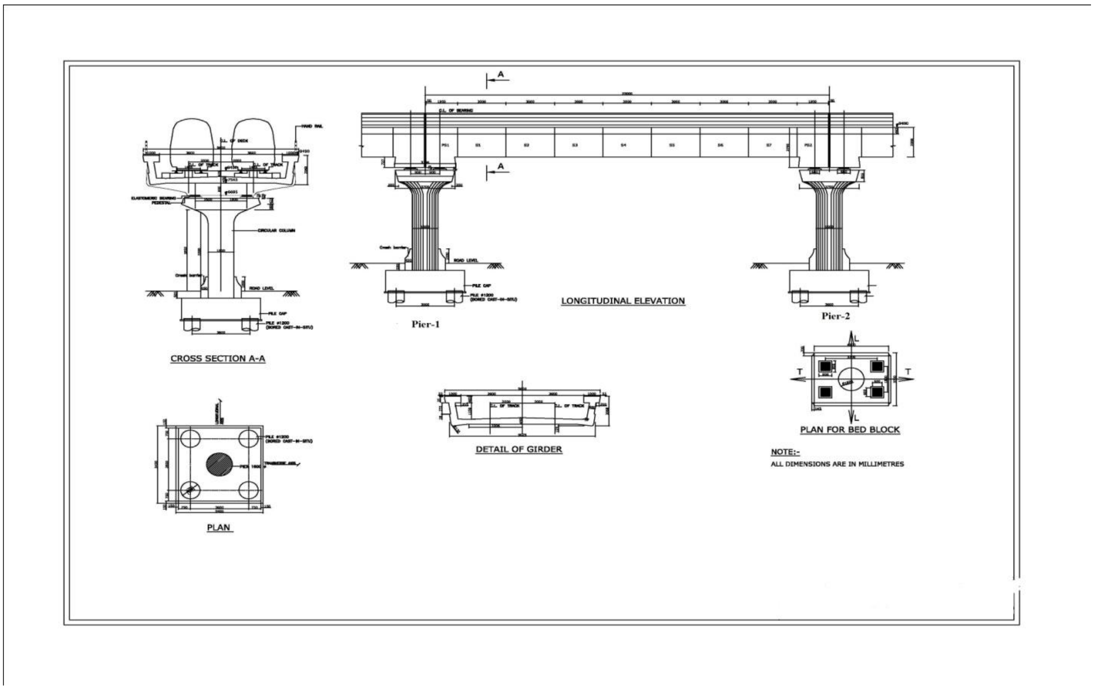

Figure 1: Plan of bridge

3.3. Analysis of Test Results:-

3.3.1. Ultrasonic Pulse Velocity Test:-

Diameter of Pier =1600mm, Height of Pier =5500mm.

Table 2: Ultrasonic pulse velocity test results

S.No.	Location	Path length (L)mm	Transit Time (T) µs	Velocity (V=L/T)km/s	Compressive Strength (f_{ck}=N/mm^2)	Arrangement
1	Pier-1.1	1273	295	4.320	46	Same Face
2	1.2	1800	462	3.90	51	Same Face
3	1.3	1273	287	4.44	61	Same Face
4	1.4	688	148	4.65	65	Same Face
5	1.5	1273	268	4.75	53	Same Face
6			**Average Pier-1**	**4.41**	**55**	
7	Pier-2.1	1663	350	4.75	67	Same Face
8	2.2	1800	371	4.85	64	Same Face
9	2.3	1663	347	4.79	62	Same Face
10	2.4	1273	266	4.79	69	Same Face
11	2.5	688	146	4.71	61	Same Face
12			**Average Pier-2**	**4.78**	**65**	
			Total Average	**4.59**	**59.5**	

Note: µs = Micro Seconds.

Average Ultrasonic Pulse (USP) Wave Velocity = (4.41+4.78)/2 = 4.59 km/sec.

3.3.2 Results:-

The Ultrasonic pulse velocity represents the quality of concrete in terms of uniformity, incidence or absence of flaws, cracks and segregation, the level of workmanship employed in concrete structure. As per the guidelines laid in IS-13311-Part 1-1992, since the USP velocity is greater than 4.5 km/sec, the concrete quality may be categorized as excellent.

3.3.3 Correlation Between compressive Strength of concrete & NDT Parameters viz. Ultrasonic Pulse Velocity test:-

In an attempt to develop correlation between compressive strength & Ultrasonic Pulse Velocity test were casted of same grades and cured and left to meet with the site conditions. A total of 2 piers each of M40 Grades concrete were obtained for testing in the sites. As per IS: 13311-1992 (part 1), the piers were tested by Ultrasonic Pulse Velocity test by holding them in compression testing machine. Ultrasonic Pulse Velocity test for same face were obtained. About 5 readings on each of piers were noted. Values of Ultrasonic Pulse Velocity test and compressive strengths of the piers are presented in table 2. Based on the procedure outlined in Is-13311-1992 (part 1) relationships between compressive strength and Rebound numbers have been developed using regression shown in figures 2 to 3. From the relevant correlation curves, most likely compressive strength of concrete has been obtained after allowing for necessary corrections.

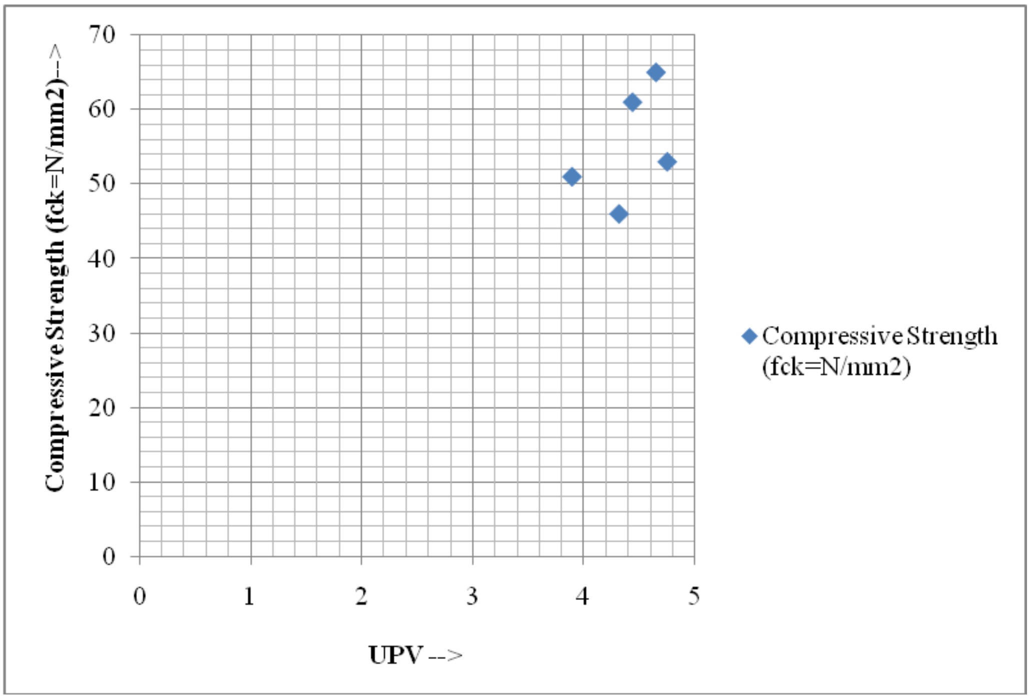

Figure 2: Correlation between Compressive Strength of Concrete & Ultrasonic Pulse Velocity Test-Pier-1

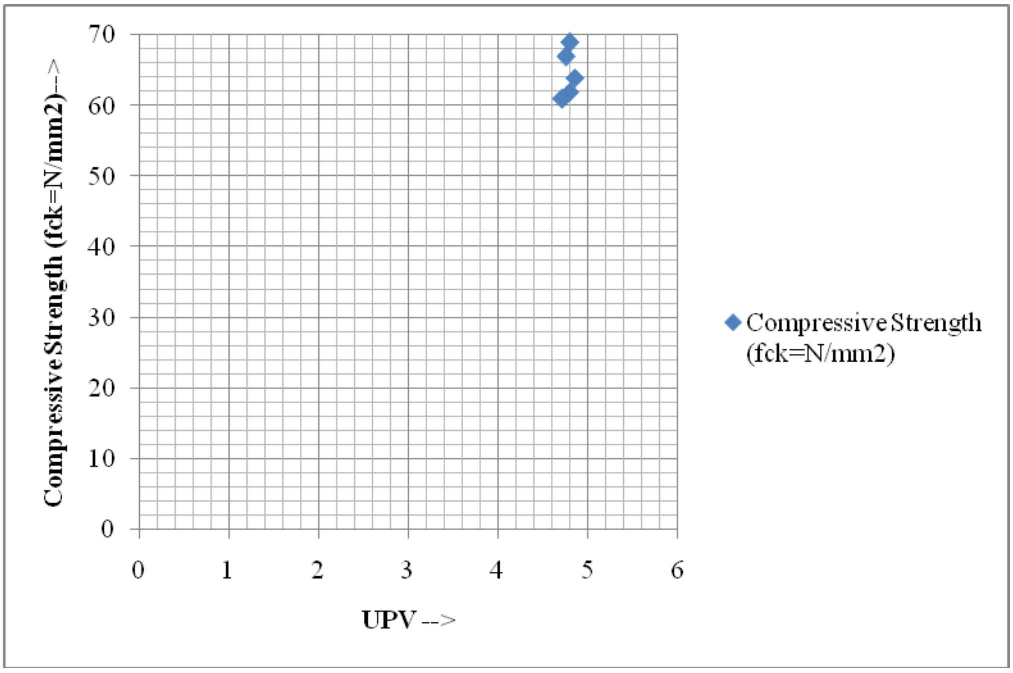

Figure 3: Correlation Between Compressive Strength Of Concrete & Ultrasonic Pulse Velocity Test-Pier-2

Using these relationships, the compressive strengths of concrete have been evaluated from the observations taken on the actual structure.

3.3.4 Compressive Strength from Ultrasonic Pulse Velocity Test:

Bridge pier-1 and pier-2, Grade adopted M40 Average value of Ultrasonic Pulse Velocity Test with same face pier-1 =4.41, pier-2=4.78.

From the correlation developed between Ultrasonic Pulse Velocity Test and compressive strength, compressive strength was obtained as pier-1= 55 MPa. , pier-2=65 MPa.

Observations on concrete on both pier. The average value of USPV for same face of both concrete pier was obtained as 4.59 km/s which as per IS:13311 (part 1) can be considered as Excellent quality concrete. From the correlation developed between USPV and compressive strength, compressive strength was obtained as 59.5 MPa.

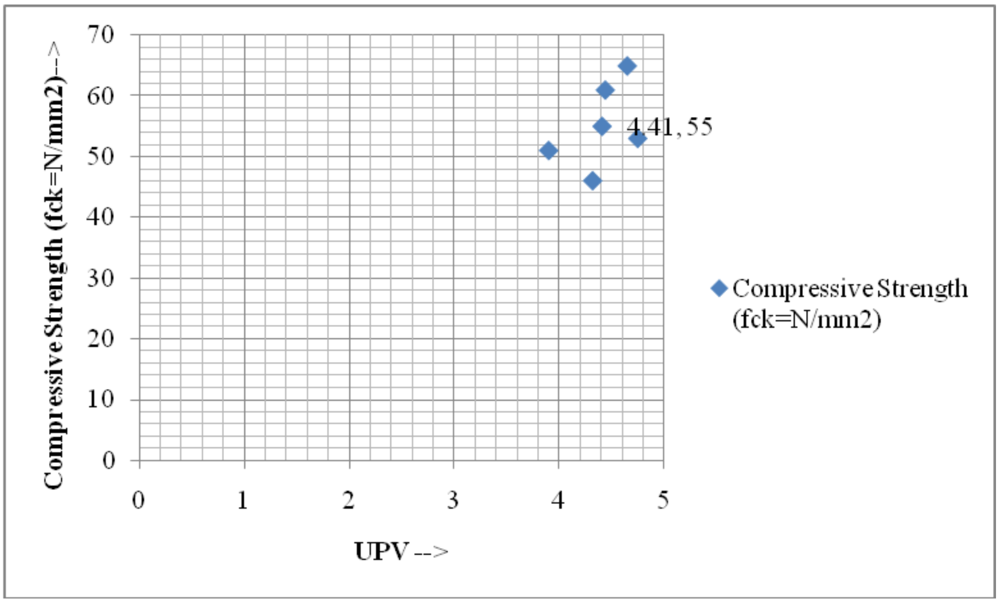

Figure 4: Correlation between Compressive Strength of Concrete & Average Ultrasonic Pulse Velocity Test-Pier-1

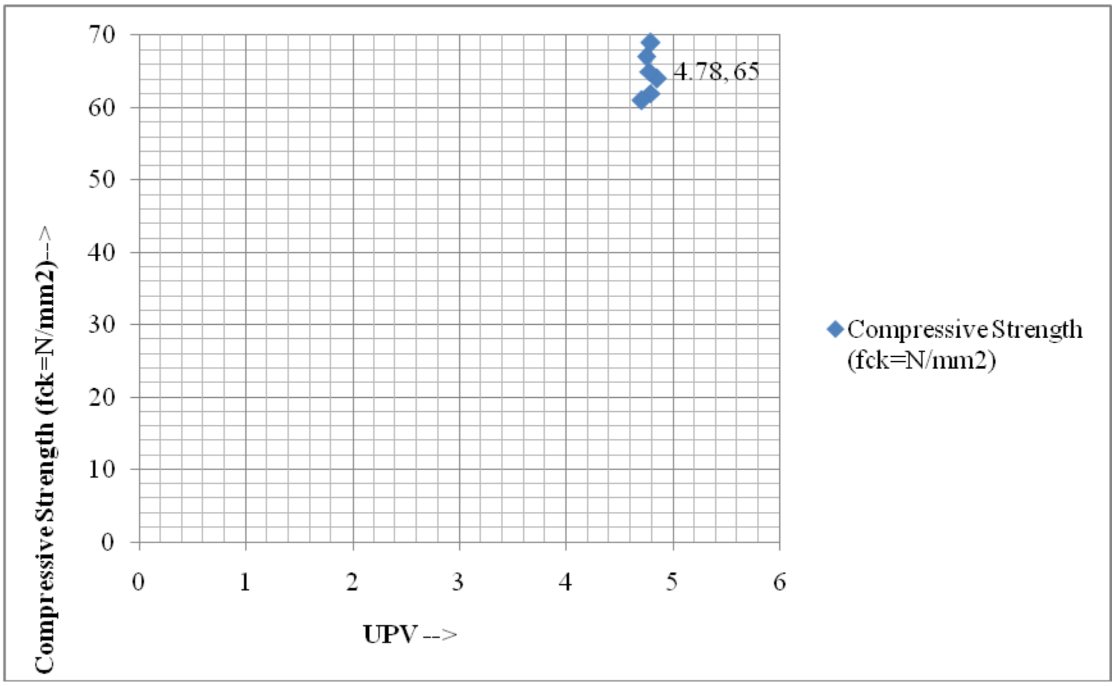

Figure 5: Correlation between Compressive Strength of Concrete & Average Ultrasonic Pulse Velocity Test-Pier-2

IV. CONCLUSION

NDT methods such as UPV very useful for predicting the service life of the structures and deterioration of the structures provided the periodical monitoring of the same member of the structures is being carried out. Since the concrete is heterogeneous and tests are affected by various factors such as age of the concrete, carbonation depth, reinforcement, cracks and voids inside the concrete, a combined test helps for assessment the strength and durability. The experimental investigation showed that a good co-relation exists between compressive strength and ultrasonic pulse velocity. Nevertheless rebound hammer should be used alone to determine the compressive strength of the structures. Ultrasonic Pulse velocity is the ideal NDT method to predict the deterioration in the structures and to determine the service life of the structures.

V. RESULTS

From the experimental data, the following conclusions can be drawn:-

1. The average of pulse velocity is 4.59 km/s far from the excellent category in concrete quality.
2. Overall of the concrete structure can be categorized as wonderful because the strength is Excellent.

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